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Sealant Longevity for Residential Ducts

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Abstract

Duct leakage is a major source of energy loss in residential buildings. Most duct leakage occurs at the connections to registers, plenums, or branches in the duct system. At each of these connections, a method of sealing the duct system is required. Typical sealing methods include tapes or mastics applied around the joints in the system. Field examinations of duct systems have shown that taped seals tend to fail over extended periods of time. The Lawrence Berkeley National Laboratory has been testing sealant longevity for several years. The accelerated test method developed by LBNL is being used as a basis for an ASTM Standard under sub-committee E6.41. LBNL tests found that typical duct tape (i.e., fabric backed tapes with rubber adhesives) fails more rapidly than all other duct sealants. LBNL has also tested advanced tape products being developed by major manufacturers. The results of these tests showed that the major weaknesses of the tapes that fail are the use of natural rubber adhesives and the mechanical properties of the backing.

Keywords: duct leakage; UL181B; duct tape; flex duct; sealant longevity

Introduction

Many studies in recent years have shown how air leaking in and out of residential duct systems results in increased energy use, increased peak demand, poor indoor air quality, poor moisture control, and other building airflow related problems. The majority of this air leakage occurs at duct system connections, where material used to seal the ducts has failed. In many failed sealant cases, the seal was no longer on the duct, but there were indications that a seal had been installed. This paper describes work performed at LBNL to examine the longevity and key performance characteristics of duct sealants. The work provides technical background for preparing an ASTM test method for duct sealant durability, test data and technical support for building code rulings on the use of duct sealants, and relative rankings of sealants so that better sealants may be selected by the building industry.

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Our test procedures follow typical accelerated aging and durability methods, in which product test samples are prepared in a standard manner and then exposed to closely-controlled continuous environmental conditions that represent extreme operational conditions expected for residential systems. This means continuously exposing the sealants to hot and cold air temperatures and pressure differences that can occur in real systems. The temperatures that we used did not exceed sealant temperature-rating limits and were substantially (more than 27°C (50°F)) below those allowed in duct systems by mechanical codes [*1,2*]. For typical duct system operation, we would not expect the systems to *continually* operate at the temperatures and pressure differences that we used. For example, most heating and cooling systems cycle on and off and are rarely continuously operating even at building design load conditions. In many situations, it is likely that a system will not experience the extremes of temperature for weeks at a time.

The work performed for this study was split into four phases, which build upon initial studies performed by the authors [*3-7*]. As the work progressed from phase to phase, the testing became more focused on specific performance issues. We started out in phase one doing tests to obtain a greater understanding of the failure mechanisms observed in the previous studies, and to broaden the testing to find more accelerated testing procedures. The second phase was performed in response to questions posed by the duct tape industry and by code authorities (primarily the California Energy Commission). In this phase, the more focused testing examined industry claims regarding the applicability of sealants. This required testing duct joints where the tape can lie flat across its width, and carrying out tests where tapes were only part of the UL sealing system[2]. Also, we carried out tests to determine if the UL branding of duct sealants provides a robust predictor of sealant performance that can be relied upon by code authorities. This third phase only tested UL181B-FX[3] [8] products. The fourth phase of testing was intended to explore the relationship between a temperature test like the one in UL 181B-FX and our more focused laboratory testing.

Our test results have been used to evaluate and support the creation of an ASTM longevity/durability test procedure within ASTM subcommittee E06.41 (Performance of Buildings - Air Leakage and Ventilation Performance). The results and experimental work discussed in this paper led to significant changes in the proposed ASTM standard, including using higher test temperatures and heating only. These changes led to a significantly simpler test procedure and a reduction in the effort (particularly in preparing the experimental apparatus) required to perform the test.

[2] The UL 181 standard only applies to sealants for flex duct to collar connections that have a clamp over the sealant as a mechanical connection to hold the flex duct core in place over the collar.

[3] The “-FX” in the UL terminology refers to pressure adhesive tape. There is also a “-M” suffix that is applied to mastic products.

Failure Criteria

The selection of failure criteria is important in any kind of testing. In each phase of testing, we determined criteria appropriate to the test. Because air leakage is the fundamental parameter of interest, we measured it whenever possible. We also made visual inspections of all joints and included the subjective criteria used in the UL standard. For the collar-to-plenum joints, we could reliably test for leakage and set a failure criterion.

The air leakage measurements were conducted periodically (typically on a monthly or weekly basis) by removing the samples from the test apparatus. They were then placed in a separate leakage testing device (Figure 1) that pressurized the samples to 25 Pa (0.1 in. water) and measured the airflow rate required to maintain the 25 Pa (0.1 in. water) pressure difference. 25 Pa (0.1 in. water) was chosen because this pressure difference is used as a reference pressure in field testing of duct system leakage (ASTM Test Methods for Determining External Air Leakage of Air Distribution Systems by Fan Pressurization E1554, [9,10,11]) and it is typical of average pressures across residential duct leaks.

This 25 Pa (0.1 in. water) airflow rate was also measured before any sealant was applied and after initial sealing. The air leakage after initial sealing was usually very small (about 0.5% of the unsealed air leakage) and accounted for the remaining leakage in the leakage test device and test sample. The difference between the air leakage before and after sealing is therefore the amount of sample leakage that has been sealed by application of the sealant. We set a failure criterion for air leakage at 10% of this difference based on what we considered to be a realistic level of leakage for an individual joint in a real system, and as a leakage level after which samples tended to fail rapidly in our testing.

When using sealants in configurations other than a collar-to-plenum joint, simple pass-fail leakage criteria are not clear-cut and must be augmented with visual inspection information.

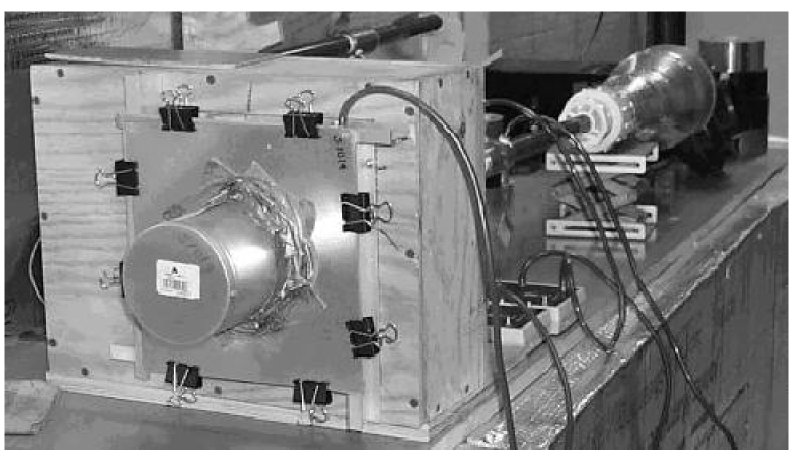

Figure 1 - *Leakage test device for pressurizing test samples. (Test sample is a collar-to-plenum joint.)*

Tests For Sealant Longevity Performance

Phase 1

For Phase 1, we constructed a test apparatus that allowed for more samples to be tested the equipment used in our previous studies. The new apparatus had three separate test chambers allowing for heating, cooling, or cycling between hot and cold test temperatures. The heating and cooling chambers each had space for eight samples. The temperature cycling chamber had space for eight samples. The sample temperatures were controlled by circulating heated or cooled air as appropriate. The heating only samples had test section surface temperatures of 66°C to 82°C (150°F to 180°F) and the cooling only samples had test section surface temperatures of 0°C to 5°C (32°F to 41°F). For the cycling tests, a cycle time of ten minutes was used that was based on the time taken to warm up and cool down the test samples between these two extremes. The pressure difference between the inside of the test samples and their surroundings ranged from 100 to 200 Pa (0.4 to 0.8 inches of water) with the higher pressure for heating. A second apparatus was also used to bake samples at a fixed high temperature (65°C (150°F)) with no pressure difference across the leaks. The joint tested in this phase was the same round collar to flat plenum (90° angle) used in previous studies. Twenty sealants were tested: 3 UL181B-FX tapes, 15 other tapes, plus UL181B-M mastic and an aerosol sealant.

Only cloth-backed rubber adhesive tapes failed. However, the range of time to failure for these types of tape was large - with some failing in a few days and others failing slowly over several weeks. Figure 2 illustrates several of the failed collar-to-plenum joint test samples. The failure of these samples was due to a combination of factors. Some samples exhibited obvious adhesive failure, with the adhesive flowing out of the seal, or hardening and becoming brittle so that it was no longer sticky. The brittle failures sometimes led to catastrophic failure where the tapes fell off the sample completely, leaving a layer of adhesive on the joint. Delamination was common, mostly because the backing shrank more than the adhesive or the reinforcing mesh. One sample failed even before it was installed in the test apparatus. The sample was prepared for testing and placed on a workbench in the laboratory for a week. The tape had peeled itself off the joint in an attempt to return to its natural shape. Some samples were removed from the apparatus after 100 days of testing to make space on the apparatus for new samples. The removed samples were those that showed insignificant changes (no failure) in the 100 days of testing.

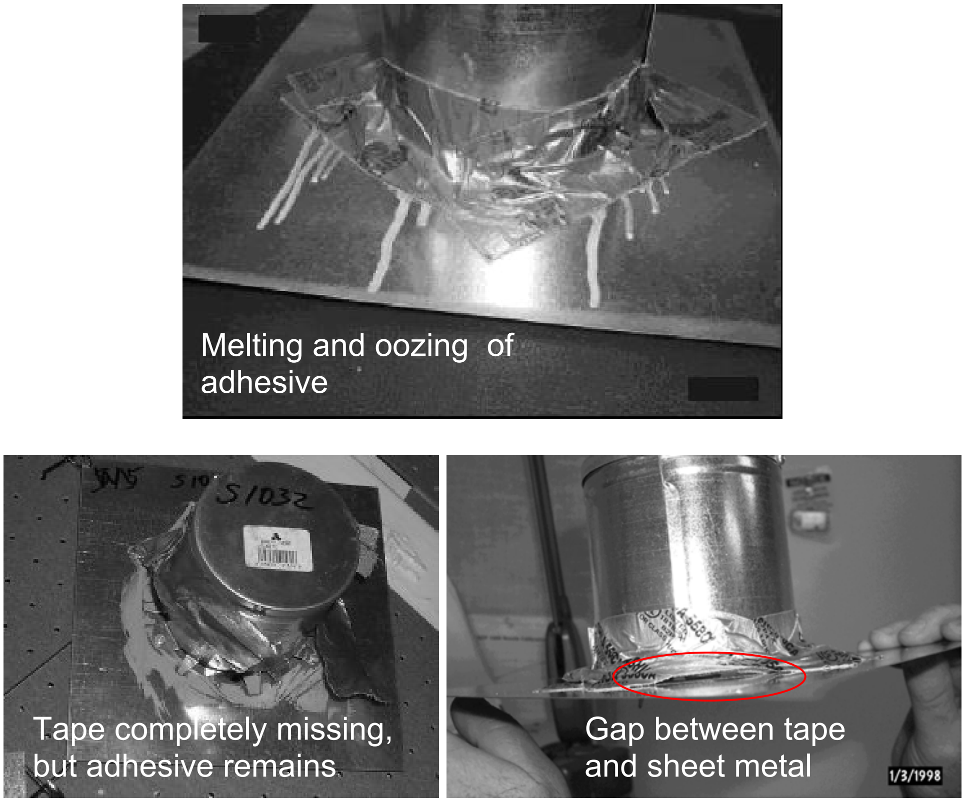

Figure 2 - *Example failures of the collar-to-plenum joint.*

The test results also showed that high temperatures were most likely to result in sealant failure. Samples exposed to the cycling temperatures took longer to fail than the heating only samples. No constantly cooled samples failed. The combination of heat and pressure difference caused more rapid failures than heat alone (as applied to the baked samples). This was because the pressure difference placed a force on the sealant such that it could move if the adhesive failed at high temperatures. Without the pressure difference, the sealant only had to support its own weight. The combined pressure and high temperature was a more realistic test for an operating duct system. This combination of results led to a rewriting of the proposed ASTM standard to use combined heat and pressure only, with no cycling of temperatures. This finding is advantageous: a simpler test apparatus can be used because no cooling equipment is required.

Phase 2

In this phase, the same apparatus as in Phase one was used, but due to equipment failure, cooling was only operative for the first two days of testing. Thereafter, the testing used heating only. Round sheet-metal connections were used for the test samples. A total of eight cloth-backed duct tapes were tested, only one of which was a UL181B-FX tape. Each sample was identically prepared using three continuous wraps of tape (i.e., a single piece of tape was wrapped around the connection three times). Figure 3 shows some of these samples installed on the test apparatus.

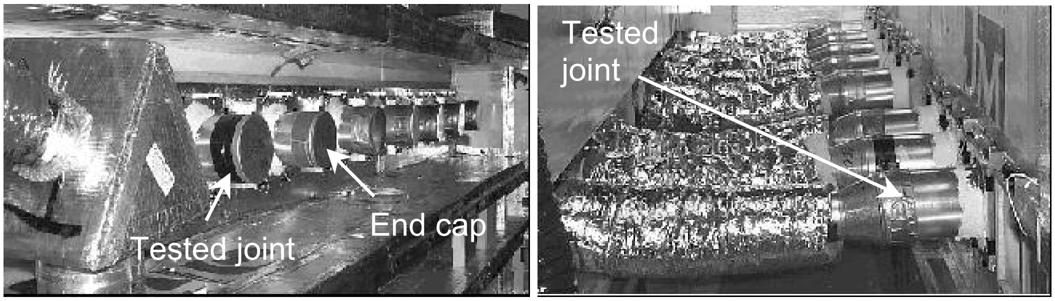

Figure 3 - *The left photograph shows test samples that had end caps together with a three-way splitter box occupying one of the test sample locations. The right photograph shows the samples that had airflow through them. Note that the collar-to-collar-to-plenum joint in these samples is sealed with mastic but it is the round-to-round sheet metal joint that is actually being tested.*

The results of this phase of testing showed that four of the tapes failed after 87 days of testing, one of which was the UL 181B-FX tape. The failed tapes were visually similar to those in Phase 1, but we did not see the catastrophic failures for a couple of reasons: The primary reason was that the round-to-round connection allowed the tape to lie flat so that the tape did not peel itself off the joint. Secondly, the outer wraps of tape tended to hold the other wraps in place. Because only one tape end was exposed at the outermost wrap, this was the only place where we observed the delamination and shrinkage of the tapes.

Phase 3

In this phase, the testing procedures were changed to specifically target UL181B-FX tapes. The rationale behind this change was that code authorities would like to be able to say that UL 181B listed sealants provide adequate duct seals, so we needed to focus on these products. In previous testing described in this paper and previous publications [1,2,5], we had found that UL181B-FX cloth backed[4] rubber adhesive tapes did not perform any better or any worse than non-UL listed cloth-backed rubber adhesive tapes. However, these previous tests had not used the sheet metal collar-to-flexible-duct-core joint that is explicitly referred to in the UL test. The argument made by the duct-tape industry was that duct tape should only be used for this collar-to-core joint and not at other joints in duct systems. Four UL181B-FX tapes were tested: two standard cloth backed rubber adhesive tapes, a polypropylene-backing acrylic adhesive tape, and a metal-foil-backing butyl adhesive tape. Tests were also done for an experimental cloth-backed tape product (with a butyl-rubber adhesive) that was applied to the collar-to-plenum joint used in previous testing. More details of the testing in phase three can be found in [12].

The test apparatus was revised to be heating only because our test results and the opinions of duct tape manufacturers agreed that the tape failures were due to exposure to high temperatures. After discussion with sealant manufacturers and comments from ASTM members on drafts of the proposed ASTM standard, the

[4] "Cloth backed" refers to tapes with a vinyl or polyethylene backing with fiber reinforcement.

testing temperature was raised to 93°C (200°F). The pressure difference across the leaks averaged 84 Pa (0.34 inch water). Under these conditions, it was generally agreed that there would be about a factor of 15 acceleration of failure.

The change to heating only operation allowed simultaneous testing of 18 samples. Figure 4 shows a schematic of the hot air circulation path in the aging test apparatus. The upper and lower test chambers are connected by insulated ducting so that the same airflows through both chambers and only one heater is required. In the previous phases of testing, the lower chamber had cold air circulating through it.

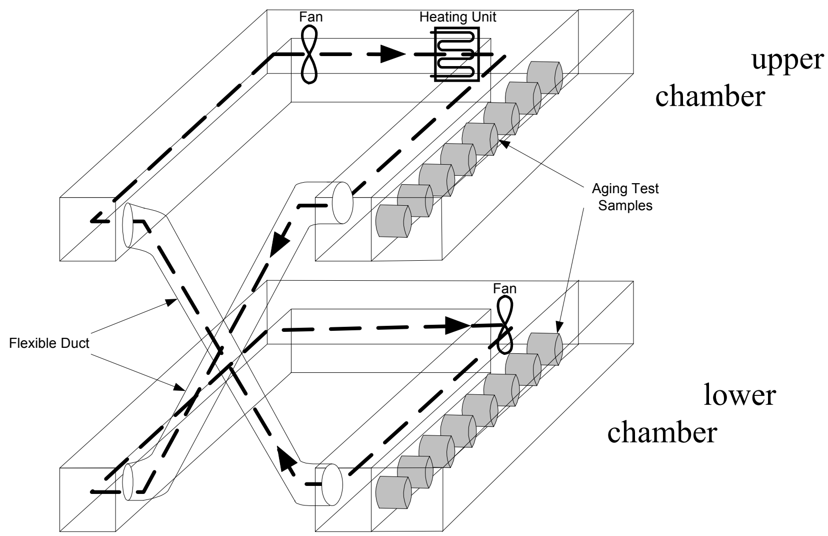

Figure 4 - *The hot air circulation in the modified longevity test apparatus*

The test samples were made from standard non-metallic flex duct core to sheet metal collar connections. All the sealants tested in this phase were evaluated using two continuous wraps of tape and with clamps over the tape (as required for a UL181B rating). Additional samples were tested with single wraps of tape and wraps made from multiple pieces of tape. We also tested samples without mechanical clamping because this configuration is commonly found in field installations. Also, clamps are only required by UL181B-FX on the inner core and not on the outer moisture barrier.

A total of 18 combinations of different tapes, taping methods, and clamping methods were tested. Each sample consisted of two taped joints at either end of a short section of flex duct core, as shown in Figure 5. The white irregular ring of material at the back (left) is mastic that has been applied over the collar-to-plenum joint. The end of the duct is capped with a metal cap that is sealed using high temperature silicone caulk before testing. Figure 6 shows a set of these samples mounted in the test apparatus.

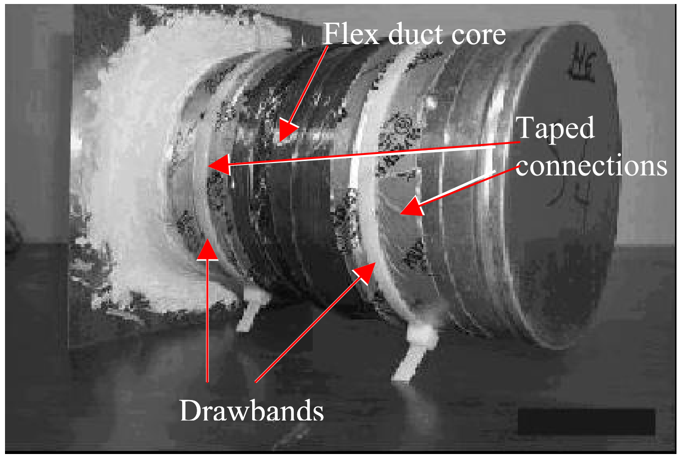

Figure 5 - *Example of test sample showing the two taped connections and the mechanical clamps.*

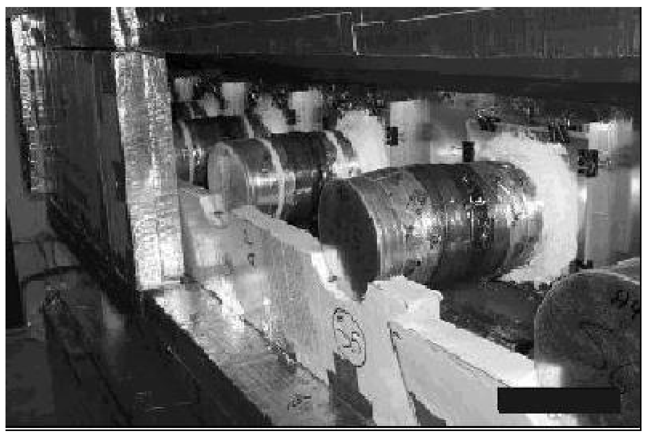

Figure 6 - *The upper chamber of the longevity test apparatus. The insulated cover has been removed for viewing. During normal operation the samples are fully enclosed inside the insulated chamber.*

The samples were visually inspected every month and their leakage was measured at the same time. Measuring the leakage of a flexible duct core-to-collar specimen prior to applying the duct tape cannot be used as a baseline leakage in the analysis. The reason is that the flexible duct does not fit firmly on the sheet metal fitting and the way the core is placed around the sheet metal collar can make a considerable difference in the amount of leakage. An unsealed specimen was tested and the leakage changed by up to 30% when the test was repeated by only changing the positioning of the flexible core around the sheet metal collar, and up to 40% among different flexible duct configurations (stretched, bent, compressed). Therefore, we considered the base case to be the initial sealing prior to testing; the failure criterion could then be characterized by the change in the leakage as well as visual inspection, rather than the fixed 10% value used in previous testing.

We took monthly photographs of all 18 samples in order to record the visual deterioration of the samples. Typical minor deteriorations were observed as discoloration, wrinkling, and oozing; major deteriorations were shrinking, peeling, delamination, and cracking. Figure 7 shows the deterioration of one of the samples with clamping, and two continuous wraps of duct tape. After the first month of aging at 93±3°C (200±°5F), all 18 samples showed the following deterioration, increasing with time:

- shrinkage and delamination among the unclamped samples (Figure 8)
- oozing of the adhesive layer in the foil-butyl tape samples (Figure 9)
- little shrinkage and delamination in the strapped samples
- discoloration of the plastic strapping in the clamped samples

The discoloration of the plastic strapping was an indication of progressive deterioration that led to a total failure in one case after four months of testing: the plastic clamp cracked open due to the increased brittleness of the plastic (Figure 10).

Figure 7 - *Illustration of visual degradation of duct tape.*

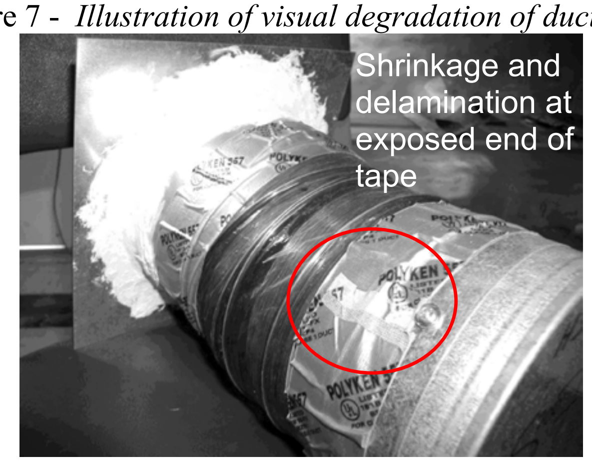

Figure 8 - *Shrinkage and delamination for an unclamped sample after 5 months of testing.*

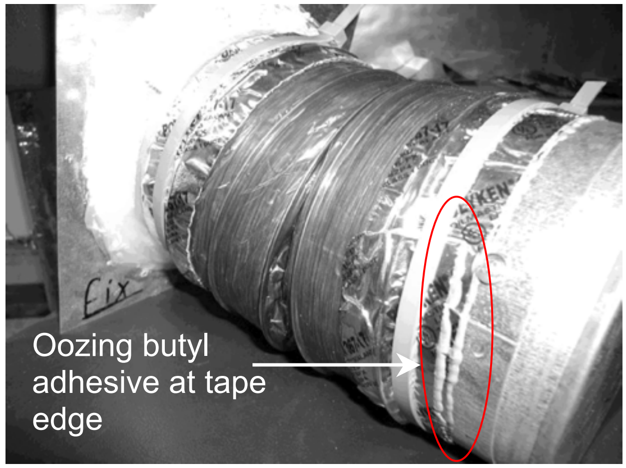

Figure 9 - *Oozing of the adhesive layer in the foil-butyl tape after 5 months of testing.*

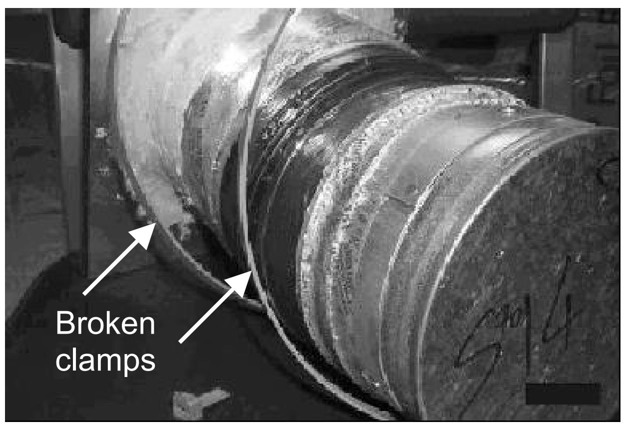

Figure 10 - *The failed plastic strapping on one of the flexible core to sheet metal collar samples after four months of testing.*

The measured leakage test results are shown in Figure 11. These results show that no overall trend was apparent: there were increases and decreases in leakage of different magnitudes for different samples. The cases of leakage decreases illustrated some of the limitations of our test procedure in terms of the resolution of the leakage tests and other issues, such as the changes due to temperature of the test sample during leakage testing. For example, for the most recent tests (the last three data points of each plot in Figure 11), we waited until the samples were cool before testing, which led to lower measured leakage. In the earlier measurements, we did not realize the importance of waiting for temperature stabilization and tested the samples at some intermediate temperature, thus leading to higher measured leakage. In addition, a general observation of the core-to-collar joints undergoing an aging test is that the shrinkage of the duct tape can have a positive effect as it tightens up around the joint, unlike the case of a collar-to-plenum joint where the shrinkage of the duct tape makes it peel off and pull away from the surface it is applied to, thus exposing the leaks.

After the initial six-month period of aging, the flexible duct core-to-collar samples showed increases in leakage, but no catastrophic failures. However, the visual inspection of the specimen showed the effects of the temperature and pressure during the aging test. The Phase 3 results presented in this paper cover approximately six months of laboratory testing, which we estimate is equivalent to between seven and eight years of field life. Since a thirty-year lifetime is often desired, we are continuing these tests.

The polypropylene tape showed the most visual deterioration, while the foil-butyl tape samples showed the least visual deterioration. The initial sample of the experimental cloth-backed tape applied to a collar-to-plenum joint failed after seven weeks. A second sample was prepared and failed after ten weeks. These are significantly better results than we have obtained previously for most cloth-backed tapes, but not as good as other sealants.

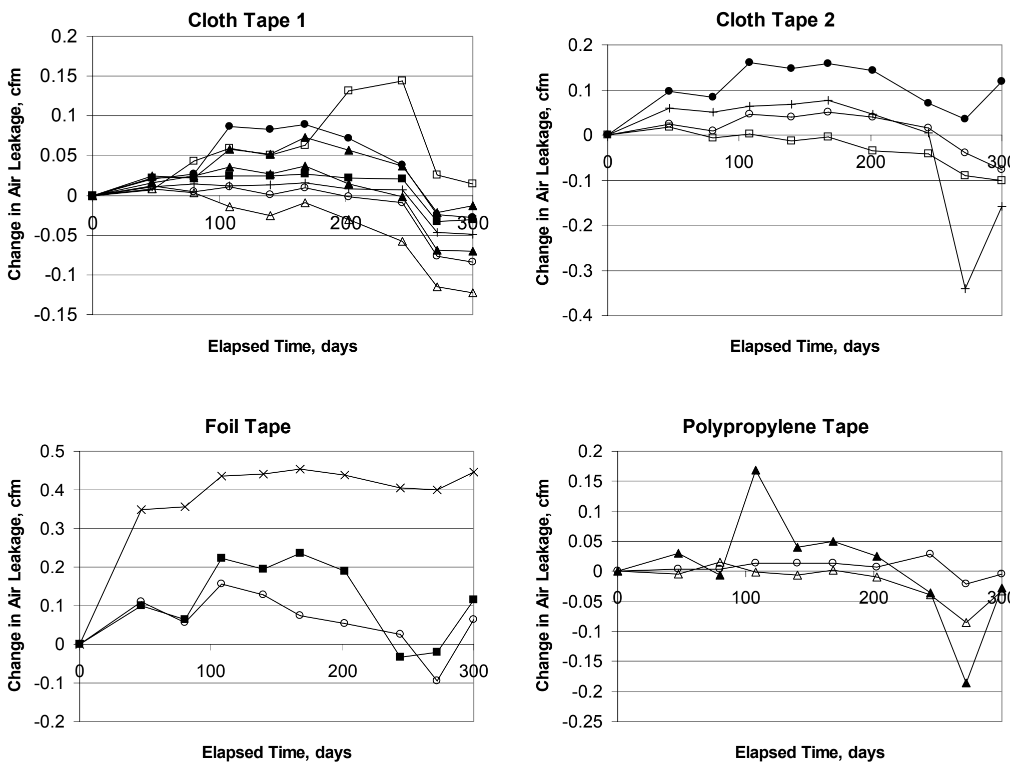

Figure 11 - *The measured change in leakage flow of the flexible core to sheet metal collar joint sample.*

Phase 4

In some of our earlier work, we had conducted “baking” tests in which sealants are kept at an elevated temperature, but without any applied pressure. In this phase of testing, the tape products of Phase 3 were tested using a test protocol similar to the temperature test of UL 181B-FX. A circulator fan was used inside the baking apparatus to ensure that the temperatures at different locations were within 2.5°C (5°F) of the target temperature of 100°C (212°F). Rather than testing sample duct connections, the baking tests in this phase used tapes that are applied to thin flat substrates of materials found in duct systems. Figure 12 shows the circulator fan and the racks inside the baking apparatus.

Figure 12 - *The high temperature baking apparatus for UL 181B testing.*

For each duct tape, twelve tape specimens were made by applying a strip of tape to three 100 by 100 mm (4 by 4 inch) samples of each of the following four materials: aluminum foil, polyethylene, polyethylene terephthalate (PET), and sheet metal (steel). Another 100 by 100 mm (4 by 4 inch) control sample of each of the substrate materials is included in the specimen set without applying the tape to it. The control sample serves as a means to quantify the deterioration attributed to the substrate in isolation from the duct tape. A specimen set in this test, therefore consists of three similar samples and one control sample, all carried by a sheet metal tray in the oven (Figure 13). Because the substrates used in this test are very thin and lightweight, they are attached from two sides to the sheet metal tray so that the fan cannot blow them away from their locations. In addition, we also placed hanging samples in the baking apparatus. These samples were attached to the top of the apparatus and had no substrate. Both the finished and the adhesive sides of the tape were exposed to the heated air, as shown in Figure 14. The samples in the baking test were tested for 60 days, with visual inspection once a week.

Visual inspection of the baking samples showed gradual deterioration in the samples over the 60 days of the test, whereas samples of the duct tape tested which were hung in the oven without being applied to any substrate showed considerable deterioration after only two weeks of baking. The rolling in most cases was a result of shrinkage in the duct tape that allows it to deform the substrate with it as it shrinks. In the case of the polyethylene substrates, the substrate itself showed some shrinkage after the second week of baking. At the end of 60 days testing, the foil-butyl tape samples showed the least deterioration, and with the sheet metal substrate showed no deterioration at all. The polypropylene tape showed the most deterioration. Its combination with the aluminum foil substrate was the worst case. The two standard duct tapes showed deterioration between these two extremes.

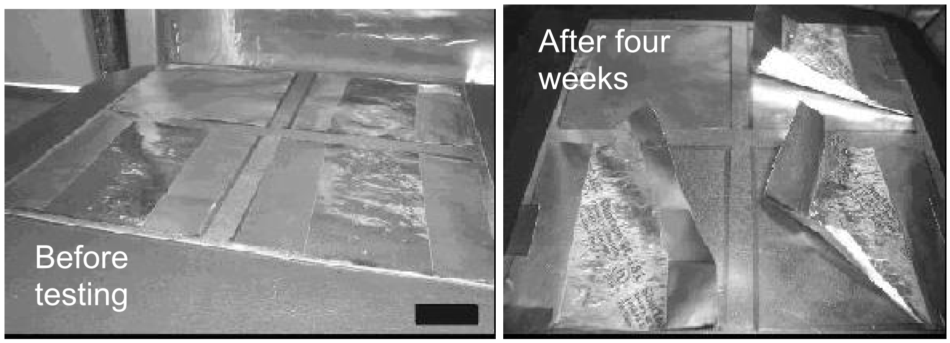

Figure 13 - *A baking specimen following the UL 181B temperature test protocol consisting of three samples of tape (Tape 3) and one control sample of the substrate (Aluminum Foil – upper left) before testing and after four weeks of testing.*

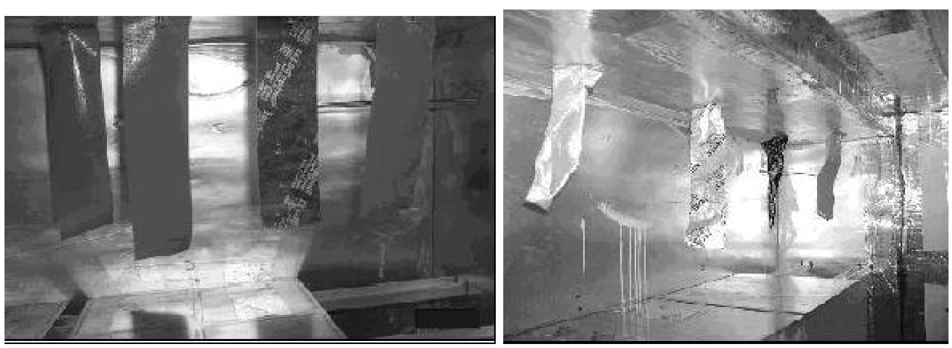

Figure 14 - *Hanging samples in the high temperature baking apparatus before testing (left) and after three weeks of testing (right).*

Conclusions

The results of our testing on the collar-to-plenum joint (principally from Phase 1) support the conclusions of our earlier work that cloth-backed rubber adhesive duct tape should not be used on this type of joint. Our results for core-to-collar joint are different. Despite visual degradation, no core-to-collar sample has had any catastrophic leakage failures in the configuration recommended by the industry and included in the UL 181B standard. Minor leakage increases have been observed, but these would need to get substantially larger to cause a sample to fail based on leakage. Continued testing is underway to extend this conclusion to a thirty-year lifetime.

Should this conclusion hold up, one could conclude that duct tape would be suitable for this specific joint following the specific application guidelines.

The issues of assuring compliance with the guidelines, assuring that the draw bands have an equivalent lifetime, and using different sealant technologies for different joints may, however, present practical limitations.

Even when there was no sign of catastrophic leakage, visual inspection showed considerable degradation. Many of the observed failures can be interpreted as shrinkage in one form or another. As indicated by our data, shrinkage more quickly leads to failures in three-dimensional joints such as the collar-to-plenum joint.

The fact that we observed clear visual failures in tapes that had passed UL 181B-FX raises some questions. Although the tapes we tested had been sent directly from the manufacturer, it is possible that tape properties change over time. Since visual inspection is quite subjective, it is possible that what we judged as failure was judged by the certifying authority to be acceptable. The duct sealant industry needs to address these issues with improved test standards. The industry test standards also need to evaluate all components of sealant systems. In particular, the UL 181B-FX standard requires the use of draw bands together with tape but does not test draw bands. We found that this can be a significant issue because the draw bands act to hold tape in place even if it has degraded, and the draw bands themselves can fail.

An ASTM standard based on the test methods used here has almost completed the ASTM balloting and review process and will be a useful tool for identifying sealants with good longevity.

Future work will build on these results and examine additional duct sealant installation issues. In particular, all of the tests discussed here used fittings that had been thoroughly cleaned and degreased. In real HVAC system installations, the fittings usually are not degreased (sheet metal fittings normally have a thin layer of oil/grease that is a remnant of the manufacturing process) and are often covered with construction debris such as sawdust. We are planning to develop a standard method for consistently dirtying duct fittings prior to longevity testing. The test results should then show how sensitive different duct sealants are to this installation problem.

Acknowledgements

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